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(54) **IMAGE CAPTURING DEVICE AND IMAGE CAPTURING METHOD**

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(57) **ABSTRACT**

The present invention is applied for an image capturing device having a light source and a camera that captures an image of a measurement subject placed in an optical path that lies between said camera itself and said light source. The image capturing device according to the present invention includes a control unit that subtracts a plurality of frame images captured by said camera during an OFF period of said light source from a plurality of frame images captured by said camera during an ON period of said light source, the number of frame images captured by said camera during the OFF period being the same as that number of frame images obtained by said camera during the ON period and integrates the differences between their images.

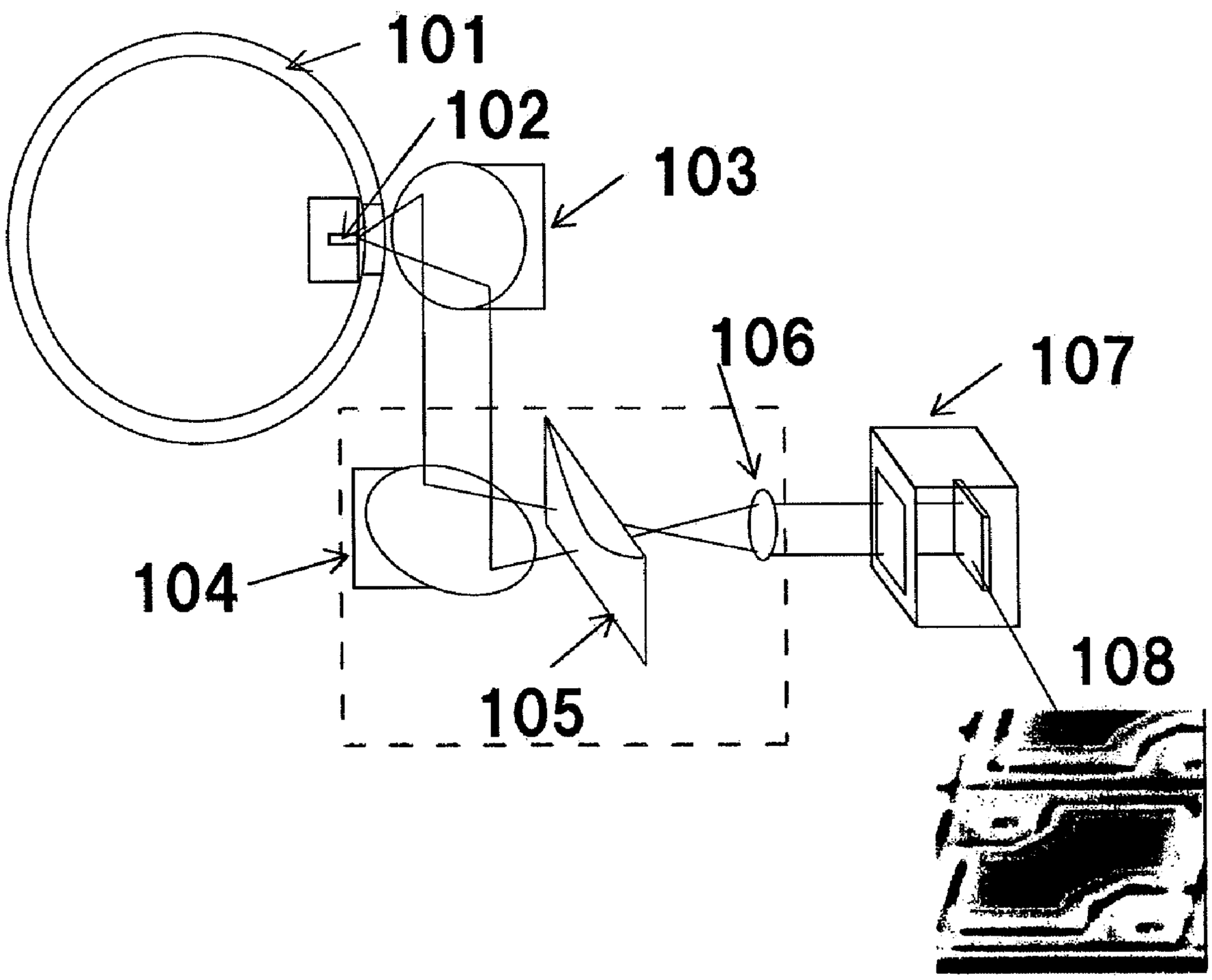
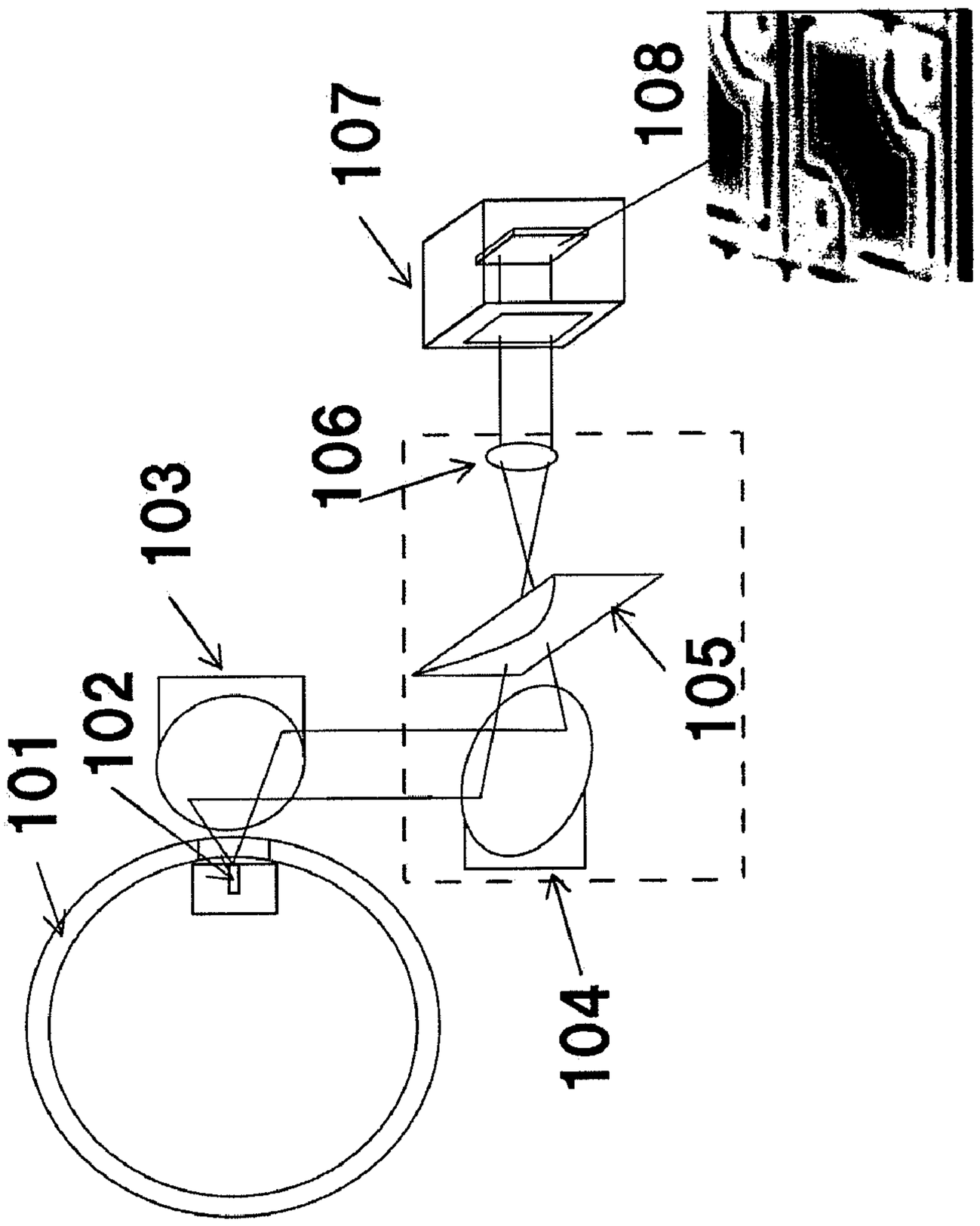


Fig.1



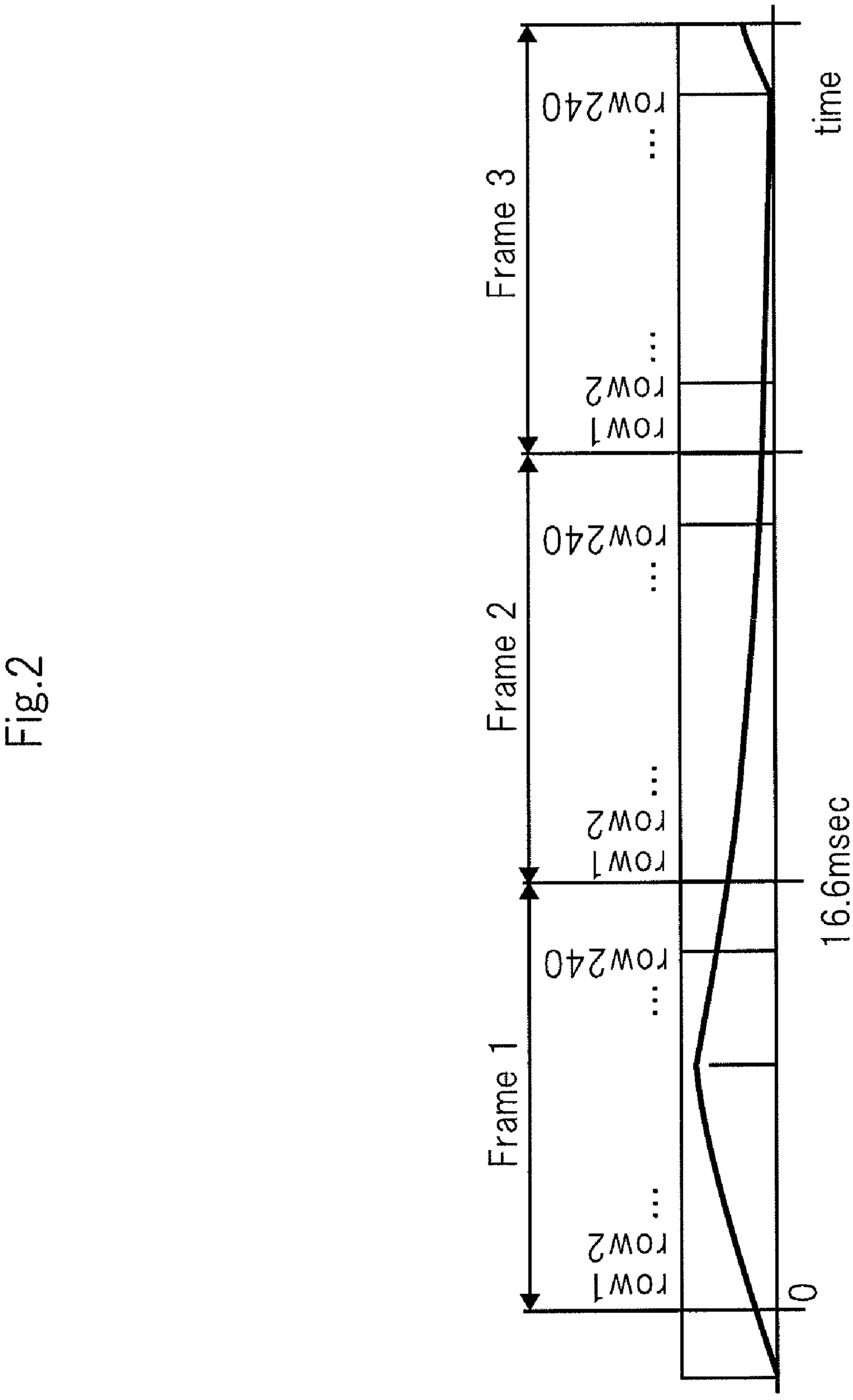


Fig.2

Fig.3

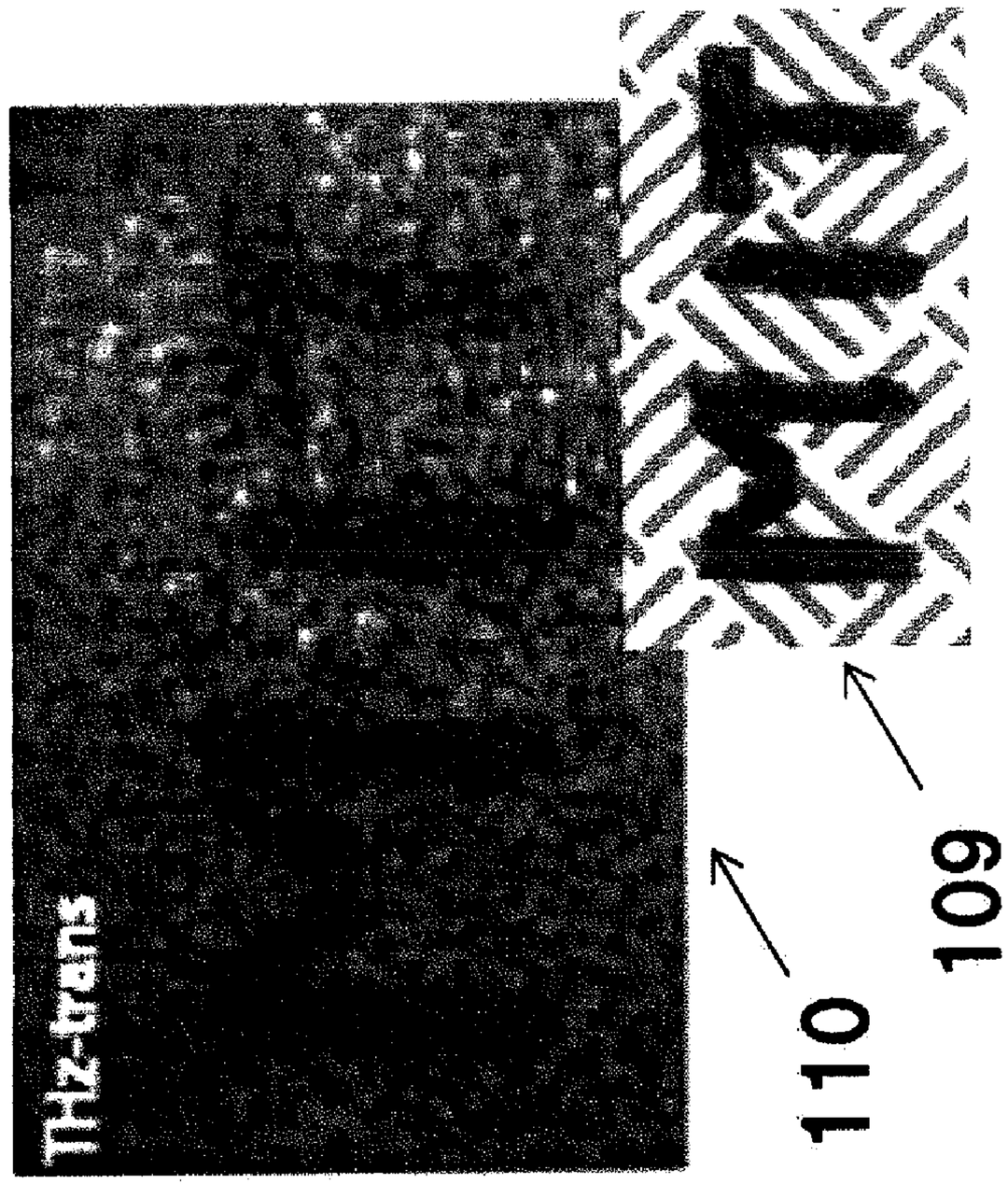


Fig.4

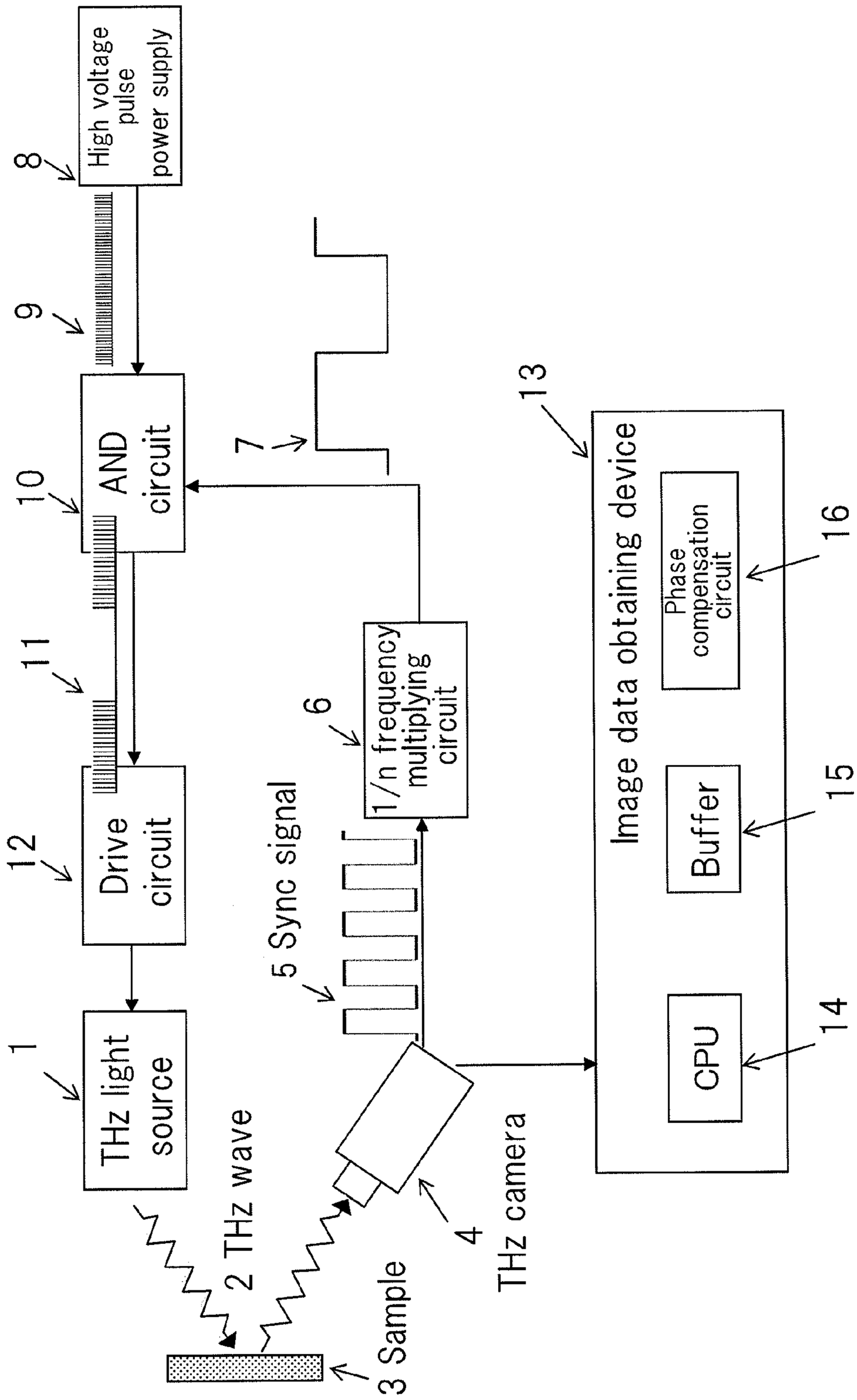

High voltage pulse power supply
8
9
AND circuit
10
11
Drive circuit
12
1/n frequency multiplying circuit
6
7
5 Sync signal
THz light source
1
2 THz wave
3 Sample
4
THz camera
13
Image data obtaining device
Phase compensation circuit
16
Buffer
15
CPU
14

Fig.5

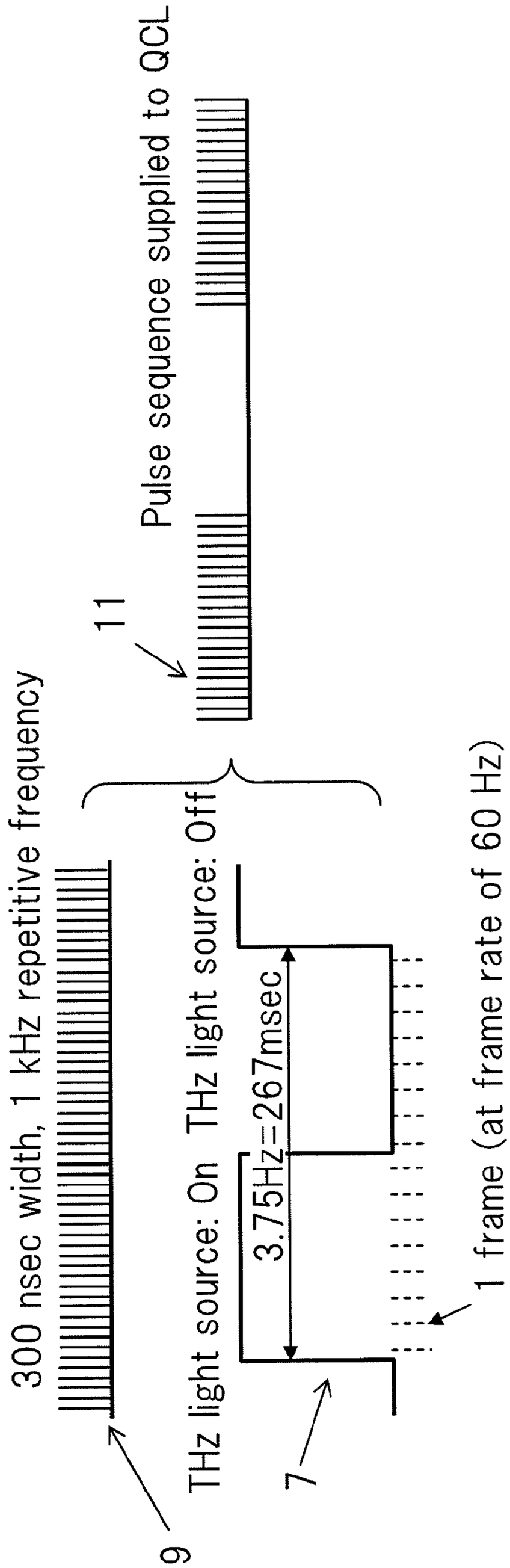

Pulse sequence supplied to QCL
11
repetitive frequency
300 nsec width, 1 kHz
THz light source: On
THz light source: Off
3.75Hz=267msec
1 frame (at frame rate of 60 Hz)
9
7

Fig.6A

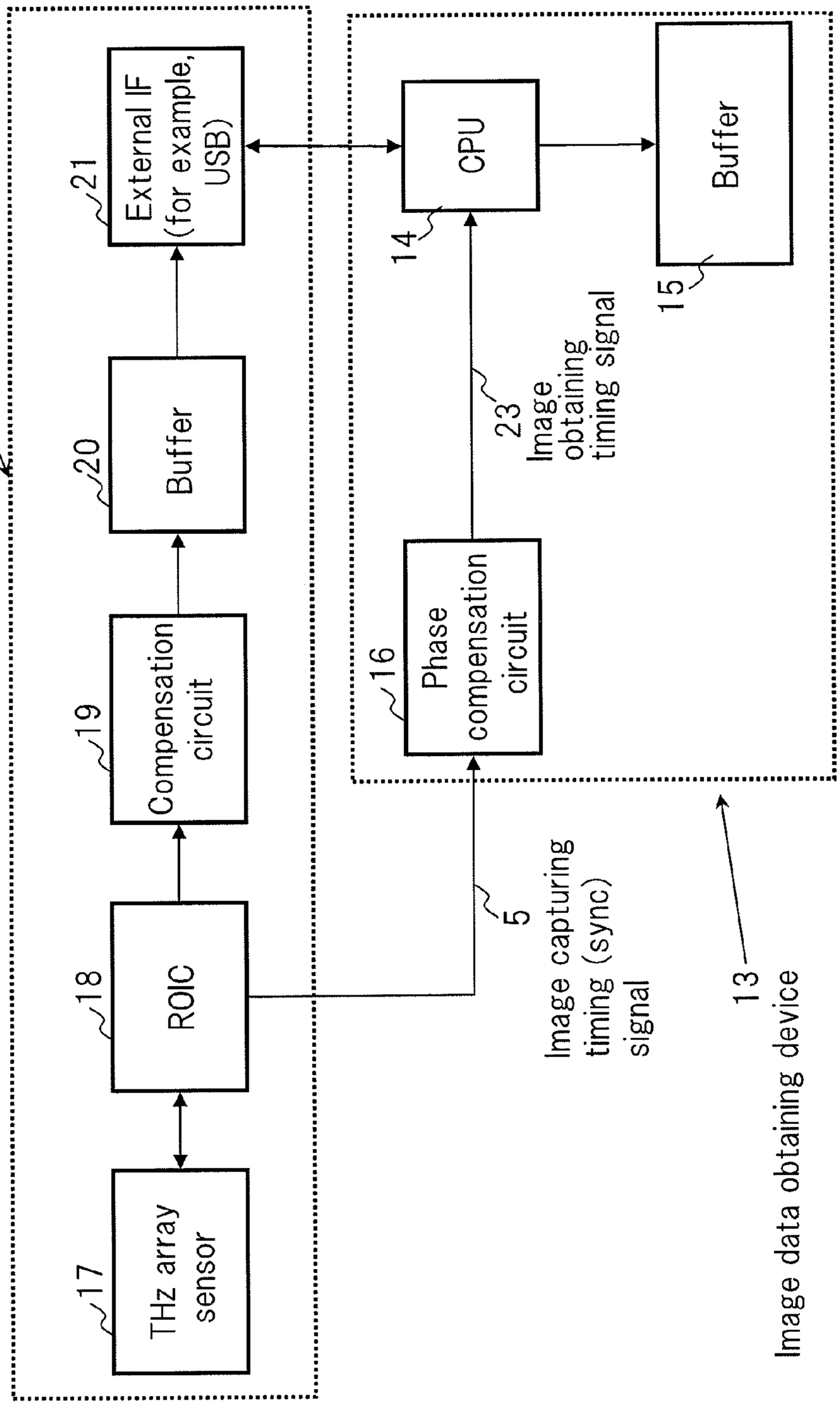

4 THz camera
21
External IF (for example, USB)
14
CPU
15
Buffer
20
Buffer
19
Compensation circuit
16
Phase compensation circuit
23
Image obtaining timing signal
18
ROIC
5
Image capturing timing (sync) signal
13
17
THz array sensor
Image data obtaining device

Fig.6B

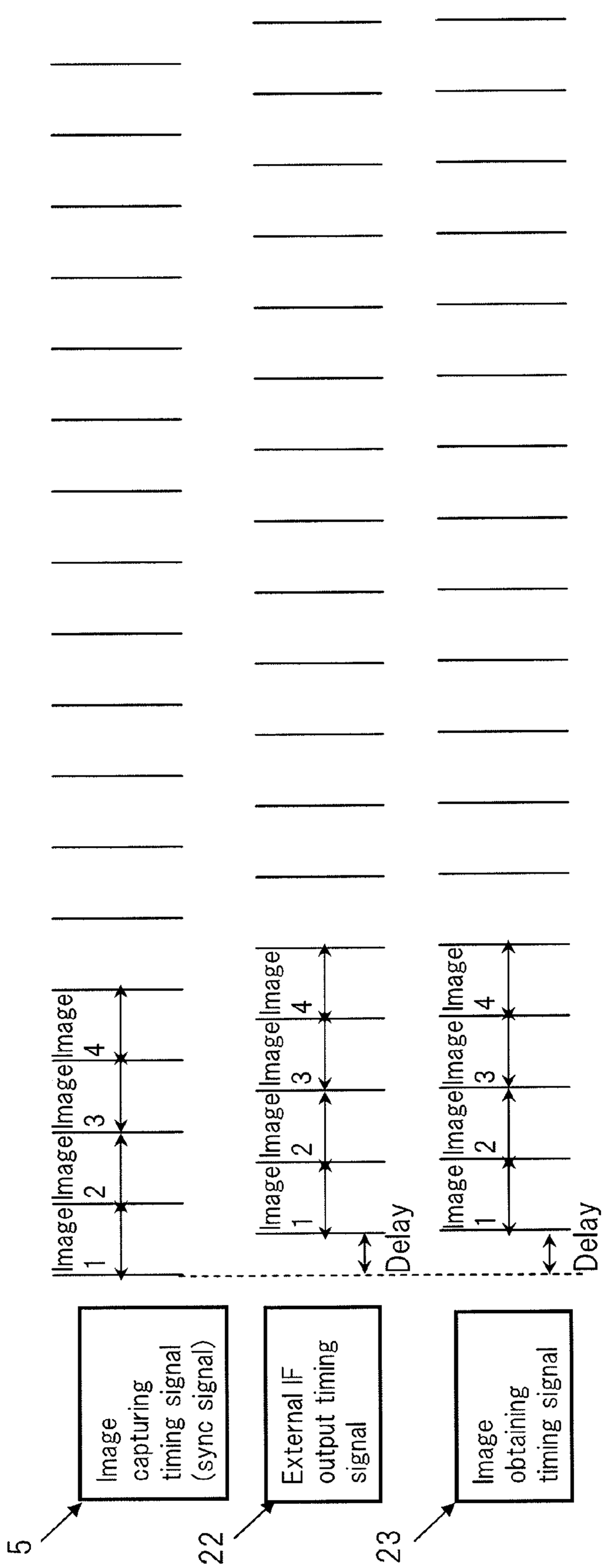

Image 1
Image 2
Image 3
Image 4
Delay
Image 1
Image 2
Image 3
Image 4
Delay
Image 1
Image 2
Image 3
Image 4
Delay
5
Image capturing timing signal (sync signal)
22
External IF output timing signal
23
Image obtaining timing signal

Fig.7A

Buffer that stores image data captured during ON state	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
Buffer that stores image data captured during OFF state	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Buffer that stores difference images	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7	Z_8

Fig.7B

Buffer that stores image data captured during ON state	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
Buffer that stores image data captured during OFF state	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Buffer that stores difference images	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8

Fig.7C

Buffer that stores image data captured during ON state	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
Buffer that stores image data captured during OFF state	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8
Buffer that stores difference images	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8

Fig.7D

Buffer that stores image data captured during ON state	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
Buffer that stores image data captured during OFF state	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
Buffer that stores difference images	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8

Fig.7E

	During ON period of THz light source								During OFF period of THz light source								
Buffer 1	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8	
Buffer 2									X_1-Y_1	X_2-Y_2	X_3-Y_3	X_4-Y_4	X_5-Y_5	X_6-Y_6	X_7-Y_7	X_8-Y_8	

Fig.7F

Buffer that stores image data captured during ON state	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
Buffer that stores image data captured during OFF state	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	Y_8

Fig.8

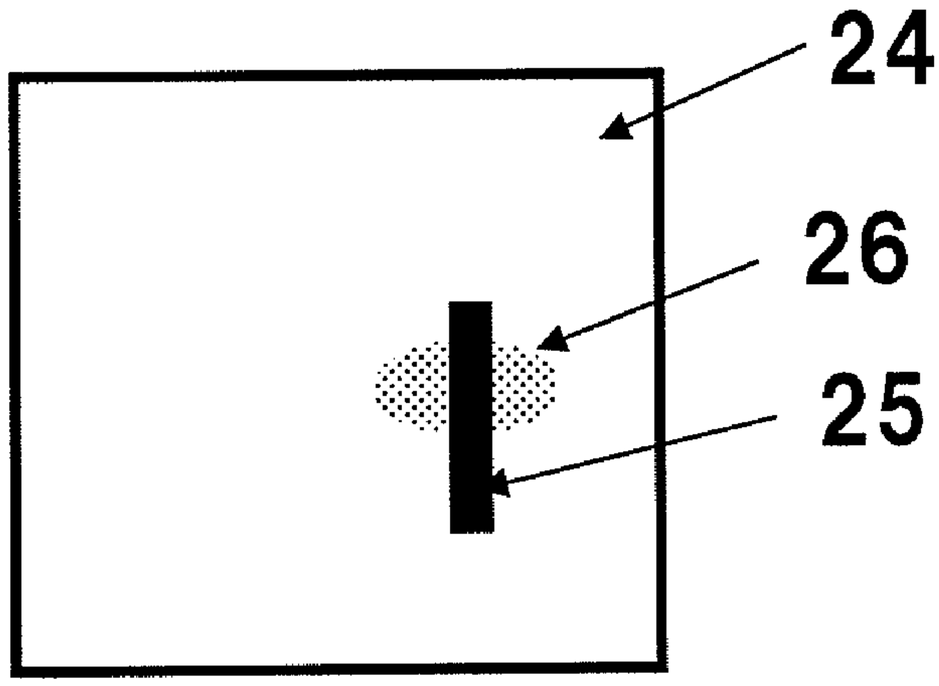


Fig.9

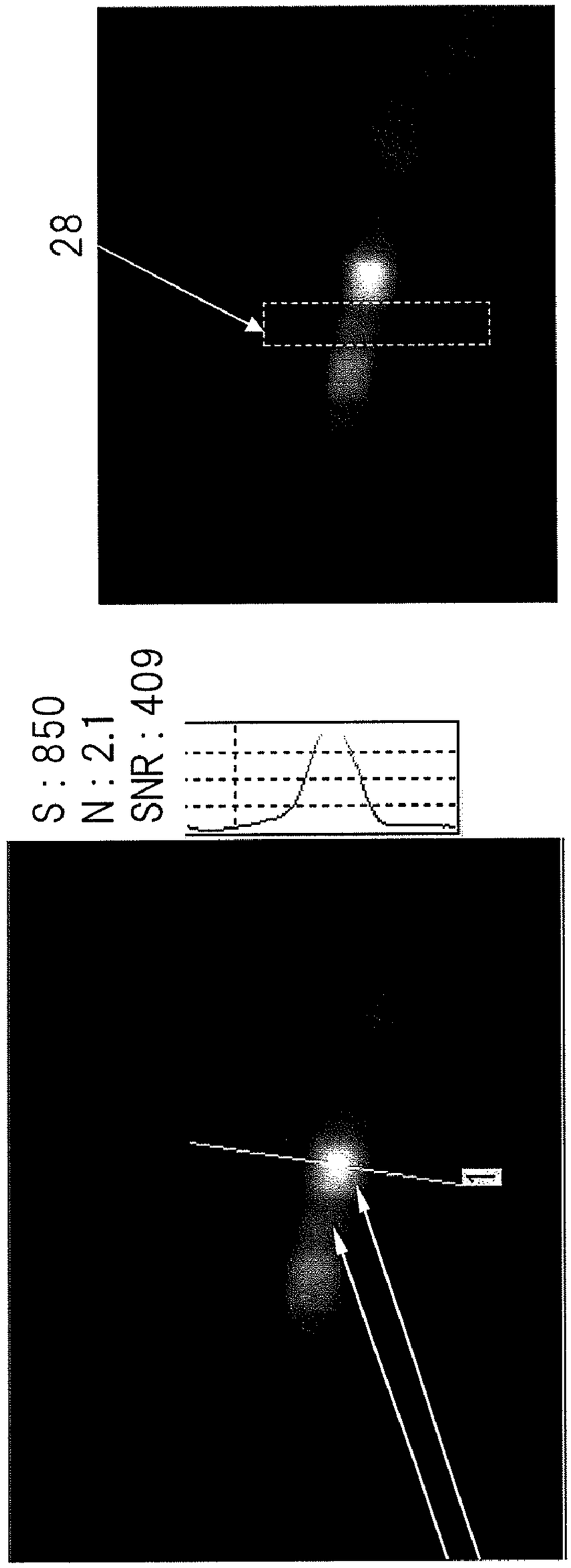

Frame integration applied
Lock-in:3.75Hz
Number of Integrated frames: 16
Number of pixels of image data integrated: 24 x 24
F Int.:Frames are integrated during ON period/OFF period
S : 850
N : 2.1
SNR : 409
28
27
29

Fig.10

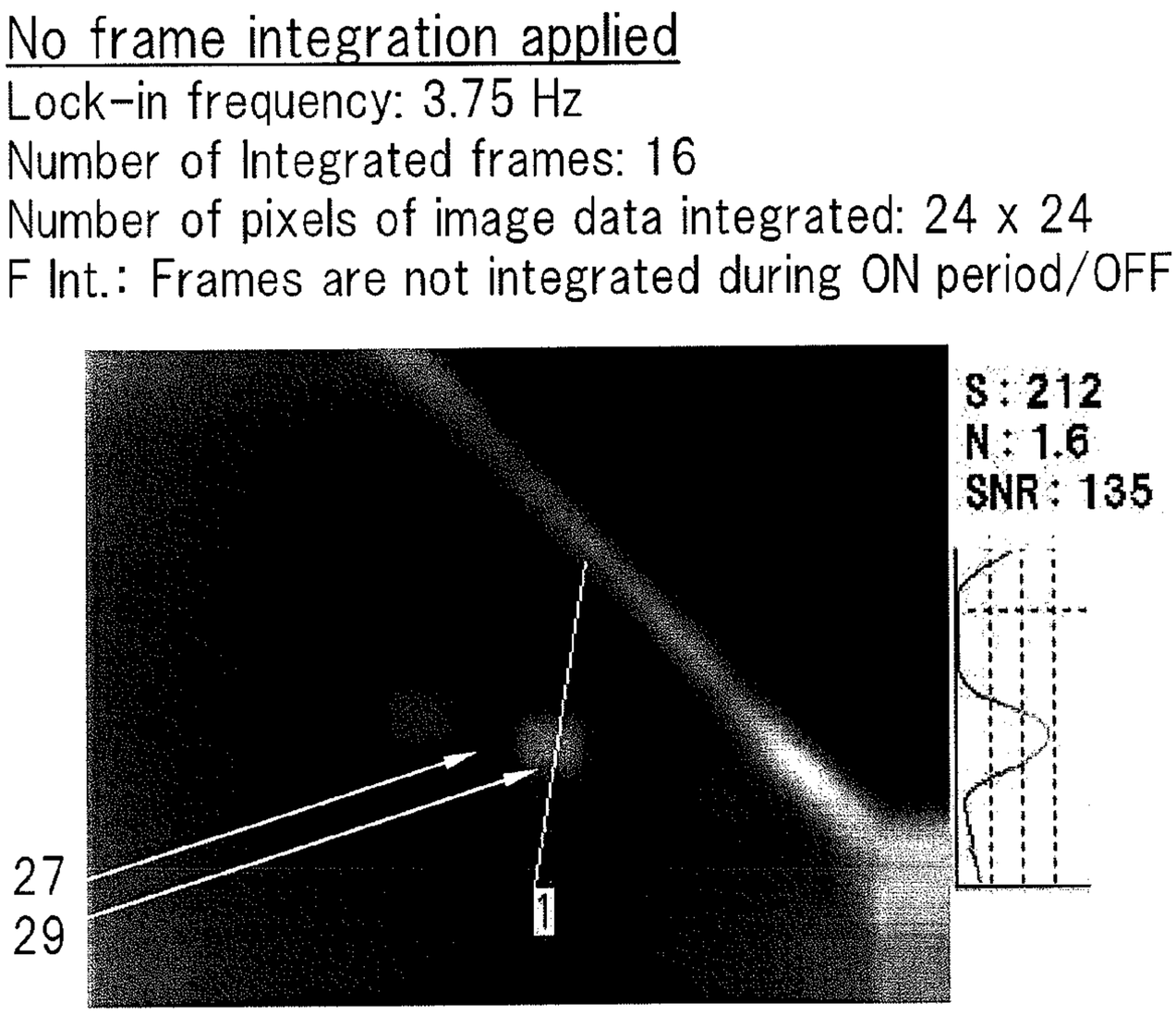

No frame integration applied
Lock-in frequency: 3.75 Hz
Number of Integrated frames: 16
Number of pixels of image data integrated: 24 x 24
F Int.: Frames are not integrated during ON period/OFF period
S: 212
N: 1.6
SNR: 135
27
29
1

IMAGE CAPTURING DEVICE AND IMAGE CAPTURING METHOD

[0001] This application is based upon and claims the benefit of priority from Japanese patent application No. 2011-070058, filed on Mar. 28, 2011, the disclosure of which is incorporated herein in its entirety by reference.

BACKGROUND OF THE INVENTION

[0002] 1. Field of the Invention

[0003] The present invention relates to an image capturing device that is provided with a light source and a camera and in which a measurement subject is placed in an optical path that lies therebetween, in particular, to an image capturing device that captures an image of a measurement subject in synchronization with ON/OFF states of the light source.

[0004] 2. Description of the Related Art

[0005] Image capturing devices that are provided with a light source and a camera and in which a measurement subject is placed in an optical path that lies therebetween are known. In these image capturing devices, when an image of a measurement subject is captured in synchronization with the ON/OFF states of the light source (so-called lock-in image capturing), not only images caused by radiations other than the light source can be eliminated, but also low-frequency noises such as 1/f noises can be set to the off setting.

[0006] For example, as presented in Non-patent Literature 1 (A. W. M. Lee et al., IEEE PHOTONICS TECHNOLOGY LETTERS, VOL 18, NO. 13, Jul. 1, 2006, p. 1415-1417), when a THz wave emitted by a THz light source that is periodically turned ON and OFF is transmitted to a camera whose sensitivity is within a range from the infrared region to the THz (terahertz) region, the camera detects an electromagnetic wave in which infrared and a periodic THz wave have been mixed and captures an image based on the detected electromagnetic wave. By calculating the difference between image data captured by the camera during the ON period of the THz light source and image data captured by the camera during the OFF period thereof, infrared images can be set off and thereby only THz images can be obtained. As a result, a filter that suppresses infrared waves and passes through only THz waves can be omitted.

[0007] A specific arrangement of the foregoing image capturing device is shown in FIG. **1**.

[0008] As shown in FIG. **1**, light of a THz wave at a frequency of 4.3 THz (with a wavelength of 70 μm) is emitted by QCL (Quantum Cascade Laser) **102** that is mounted on cooler **101**. The light travels to off-axis parabolic mirror **103**. Off-axis parabolic minor **103** collimates the light and reflects the collimated light to off-axis parabolic mirror **104**. Off-axis parabolic mirror **104** radiates the collimated light to envelop (measurement subject) **105**. The light that has passed through envelop **105** is collected by Si lens **106** to microbolometer array sensor **108** that has 320×240 pixels and that is mounted on microbolometer camera **107** (at a frame rate of 60 Hz). Microbolometer array sensor **108** captures an image based on the collected light of the THz wave.

[0009] FIG. **2** shows a lock-in image capturing method for the image capturing device shown in FIG. **1**.

[0010] As shown in FIG. **2**, QCL **102** is turned ON at frame 1 and QCL **102** is turned OFF at frame 2 and frame 3.

[0011] At frame 1, an infrared wave and THz wave emitted by QCL **102** are collected to microbolometer array sensor **108** and thereby an image is captured based on both the infrared and THz wave, whereas at frame 2 and frame 3, only infrared waves are collected to microbolometer array sensor **108** and thereby an image is captured based on only the infrared.

[0012] Thus, by calculating the difference between the image data of frame 1 and the image data of frame 3, a THz image can be obtained as an image captured based on only the THz wave emitted by QCL **102**.

[0013] Frame 2 is not used in order to increase the difference between image data of frame 1 and image data of frame 3 since a sufficiently long time elapses after the image data of frame 1 has been captured compared to a thermal time constant of around 13 msec of microbolometer array sensor **108**.

[0014] FIG. **3** shows THz image **110** that is captured from envelop **105** that contains paper **109** with letters "MIT" written with a pencil at a frame rate of 20 Hz based on the method shown in FIG. **2**. Thus, letters "MIT" can be checked out without necessity of opening envelop **105**.

[0015] However, in the foregoing image capturing device, since only the difference between one piece of image data captured during the ON period of the light source and one piece of image data captured during the OFF period thereof, as a problem that would arise, the signal-to-noise ratio could not be improved as expected.

SUMMARY OF THE INVENTION

[0016] Therefore, an object of the present invention is to provide an image capturing device and an image capturing method that can solve the foregoing problem.

[0017] A first image capturing device according to the present invention is an image capturing device having a light source and a camera that captures an image of a measurement subject placed in an optical path that lies between said camera itself and said light source, comprising:

[0018] a control unit that subtracts a plurality of frame images captured by said camera during an OFF period of said light source from a plurality of frame images captured by said camera during an ON period of said light source, the number of frame images captured by said camera during the OFF period being the same as that number of frame images obtained by said camera during the ON period and integrates the differences between their images.

[0019] A second image capturing device according to the present invention is an image capturing device having a light source and a camera that captures an image of a measurement subject placed in an optical path that lies between said camera itself and said light source, comprising:

[0020] a control unit that integrates a plurality of frame images captured by said camera during an ON period of said light source, integrates a plurality of frame images captured by said camera during an OFF period of said light source, the number of frame images captured by said camera during the ON period being the same as the number of frame images captured by said camera during the OFF period, subtracts an integrated image of the frame images captured by said camera during the OFF period of said light source from an integrated image of the frame images captured by said camera during the ON period of said light source, and obtains the difference between their images.

[0021] A first image capturing method according to the present invention is an image capturing method for an image capturing device having a light source and a camera that

captures an image of a measurement subject placed in an optical path that lies between said camera itself and said light source, comprising:

[0022] subtracting a plurality of frame images captured by said camera during an OFF period of said light source from a plurality of frame images captured by said camera during an ON period of said light source, the number of frame images captured by said camera during the OFF period being the same as the number of frame images captured by said camera during the ON period, and integrating the differences between their images.

[0023] A second image capturing method according to the present invention is an image capturing method for an image capturing device having a light source and a camera that captures an image of a measurement subject placed in an optical path that lies between said camera itself and said light source, comprising:

[0024] integrating a plurality of frame images captured by said camera during an ON period of said light source;

[0025] integrating a plurality of frame images captured by said camera during an OFF period of said light source, the number of frame images captured by said camera during the OFF period being the same as the number of frame images captured by said camera during the ON period; and

[0026] subtracting an integrated image of the frame images captured by said camera during the OFF period of said light source from an integrated image of the frame images captured by said camera during the ON period of said light source and obtaining the difference between their images.

[0027] According to the first image capturing device and the first image capturing method of the present invention, a plurality of frame images captured during an OFF period of a light source are subtracted from a plurality of frame images captured during an ON period thereof, the number of frame images captured during the ON period being the same as the number of frame images captured during the OFF period, and then the differences between their images are integrated.

[0028] According to a second image capturing device and a second image capturing method of the present invention, an integrated image of a plurality of frame images captured during an OFF period of a light source is subtracted from an integrated image of a plurality of frame images captured during an ON period thereof, the number of frame images captured during the OFF period being the same as the number of frame images captured during the ON period, and the difference between the images is obtained.

[0029] Thus, as an effect of the present invention, the signal-to-noise ratio can be improved compared to the related art in which the difference between one image captured during an ON period of a light source and one image captured during an OFF period thereof is calculated and the difference between the images is obtained.

[0030] The above and other objects, features, and advantages of the present invention will become apparent from the following description with reference to the accompanying drawings which illustrate examples of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0031] FIG. **1** is a schematic diagram showing a structure of an image capturing device according to a related art;

[0032] FIG. **2** is a schematic diagram describing a method to obtain the difference between their images for the image capturing device according to the related art;

[0033] FIG. **3** is a schematic diagram showing a THz transmission image captured by the image capturing device according to the related art;

[0034] FIG. **4** is a schematic diagram showing a structure of an image capturing device according to an exemplary embodiment of the present invention;

[0035] FIG. **5** is a schematic diagram describing a pulse sequence used in the image capturing device according to the exemplary embodiment of the present invention;

[0036] FIG. **6**A is a schematic diagram describing a function that compensates phases of image data for the image capturing device according to the exemplary embodiment of the present invention;

[0037] FIG. **6**B is a schematic diagram describing the relationship among an image capturing timing signal, an external IF output timing signal, and an image obtaining timing signal for the image capturing device according to the exemplary embodiments of the present invention;

[0038] FIG. **7**A is a schematic diagram describing a first method for an image capturing device according to an exemplary embodiment of the present invention in which images captured during an ON period of a THz light source, images captured during an OFF period thereof, and the differences between their images are stored;

[0039] FIG. **7**B is a schematic diagram describing a second method for an image capturing device according to an exemplary embodiment of the present invention in which images captured during an ON period of a THz light source, images captured during an OFF period thereof, and the differences between their images are stored;

[0040] FIG. **7**C is a schematic diagram describing a third method for an image capturing device according to an exemplary embodiment of the present invention in which images captured during an ON period of a THz light source, images captured during an OFF period thereof, and the differences between their images are stored;

[0041] FIG. **7**D is a schematic diagram describing a fourth method for an image capturing device according to an exemplary embodiment of the present invention in which images captured during an ON period of a THz light source, images captured during an OFF period thereof, and the differences between their images are stored;

[0042] FIG. **7**E is a schematic diagram describing a fifth method for an image capturing device according to an exemplary embodiment of the present invention in which images captured during an ON period of a THz light source, images captured during an OFF period thereof, and the differences between their images are stored;

[0043] FIG. **7**F is a schematic diagram describing a method for an image capturing device according to an exemplary embodiment of the present invention in which images captured during an ON period of a THz light source and images captured during an OFF period thereof are stored;

[0044] FIG. **8** is a schematic diagram describing a sample used for an image capturing device according to an exemplary embodiment of the present invention;

[0045] FIG. **9** is a schematic diagram showing a difference in an image in which an integrated image of a plurality of images of the sample shown in FIG. **8** captured during an OFF period of a THz light source is subtracted from an integrated image of a plurality of images of the sample shown in FIG. **8** captured during an ON period thereof for an image capturing device according to an exemplary embodiment of the present invention; and

[0046] FIG. **10** is a schematic diagram showing a difference between images in which one image captured from the sample shown in FIG. **8** during an OFF period of a THz light source is subtracted from one image captured from the sample shown in FIG. **8** during an ON period thereof for the image capturing device according to the related art.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0047] Next, with reference to the accompanying drawings, exemplary embodiments of the present invention will be described.

[0048] FIG. **4** shows a structure of an image capturing device according to an exemplary embodiment of the present invention.

[0049] As shown in FIG. **4**, the image capturing device according to this exemplary embodiment has THz light source **1**, THz camera **4**, 1/n frequency multiplying circuit **6**, high voltage pulse power supply **8**, AND circuit **10**, drive circuit **12**, and image data obtaining device **13**. Image data obtaining device **13** has CPU **14**, buffer **15**, and phase compensation circuit **16**.

[0050] In FIG. **4**, CPU **14** is an example of a control unit; high voltage pulse power supply **8** is an example of a first pulse circuit; and 1/n frequency multiplying circuit **6** is an example of a second pulse circuit.

[0051] THz wave **2** emitted by THz light source **1** is radiated to sample (measurement subject) **3** and then detected as a reflected wave or transmitted wave and captured as an image by THz camera **4**. According to this exemplary embodiment, it is assumed that THz wave **2** is detected as a reflected wave.

[0052] Sync signal (image capturing timing signal) **5** that represents an image capturing timing of THz camera **4** is input from THz camera **4** to 1/n frequency multiplying circuit **6**. 1/n frequency multiplying circuit **6** multiplies the frequency of sync signal **5** by 1/n and thereby generates pulse sequence **7** (second pulse sequence).

[0053] Pulse sequence **7** is input to AND circuit **10** along with pulse sequence **9** (first pulse sequence) supplied from high voltage pulse power supply **8**. AND circuit **10** generates new pulse sequence **11** (third pulse sequence) based on pulse sequence **7** and pulse sequence **9**.

[0054] Pulse sequence **11** is input to drive circuit **12** and then drive circuit **12** causes THz light source **1** to oscillate (drive) based on pulse sequence **11**.

[0055] THz camera **4** causes the ON/OFF periods of THz light source **1** to synchronize with image capturing timings of THz camera **4** so as to perform lock-in image capturing for sample **3**. Image data of frame images captured by THz camera **4** (hereinafter frame images are simply referred to as images) are recorded to image data obtaining device **13**.

[0056] Here, a specific working example of the image capturing device according to this exemplary embodiment will be described.

[0057] THz light source **1** is a QCL (Quantum Cascade Laser) that radiates an emission line at a frequency of 3.1 THz.

[0058] Pulse sequence **9** that is supplied from high voltage pulse power supply **8** has a pulse width of 300 nsec and a repetition frequency of 1 kHz.

[0059] Sync signal **5** that is output from THz camera **4** is a square wave at a frequency of 60 Hz.

[0060] 1/n frequency multiplying circuit **6** multiplies the frequency of sync signal **5** by 1/n (where n is any value that can be set) and thereby generates square pulse sequence **7** at a frequency of, for example, 15 Hz, 7.5 Hz, or 3.75 Hz. The frequency of pulse sequence **7** is referred to as the lock-in frequency.

[0061] Pulse sequence **7** is input to AND circuit **10** along with pulse sequence **9**. Thereafter, AND circuit **10** performs an AND operation for pulse sequence **7** and pulse sequence **9** and thereby generates pulse sequence **11**. Drive circuit **12** causes THz light source (QCL) **1** to oscillate based on pulse sequence **11**. FIG. **5** shows an example that the lock-in frequency is 3.75 Hz.

[0062] As shown in FIG. **5**, when the frequency of pulse sequence **7** is 3.75 Hz, eight images are captured by THz camera **4** at a frame rate of 60 Hz during an ON period of 133.3 msec of THz light source (QCL) **1** and the captured image data are recorded to image data obtaining device **13** so as to perform an image process, for example, an integration process. In the following, it is assumed that the lock-in frequency is 3.75 Hz.

[0063] Here, with reference to FIG. **6**A and FIG. **6**B, functions of phase compensation circuit **16** disposed in image data obtaining device **13** will be described.

[0064] As shown in FIG. **6**A, THz camera **4** has THz array sensor **17**, read out integrated circuit (ROIC) **18**, compensation circuit **19**, buffer **20**, and external IF (interface) **21** such as a USB (Universal Serial Bus).

[0065] In THz camera **4**, ROIC **18** that is a member of THz array sensor **17** obtains image data captured by THz array sensor **17** in synchronization with sync signal **5**. As a result, image data are updated (hereinafter the image data are referred to as internal image data).

[0066] Moreover, in THz camera **4**, compensation circuit **19** performs a compensation process for image data so as to alleviate influence of various disturbances such as sensitivity fluctuations of individual sensor elements of THz array sensor **17** and those caused by fluctuations of environmental temperatures.

[0067] Compensation circuit **19** outputs compensated image data to the outside of THz camera **4** (hereinafter, this image data are referred to as external output image data). Thus, the update timing of the external output image data differs from that of the internal image data. Since the external output image data are output to external IF **21** through buffer **20** disposed in THz camera **4** so as to prevent data from being lost, the update timing of the external output image data further deviates. For example, when the compensation process is performed using two buffers of a data update writing buffer and an external IF output read buffer, the update timing deviates for one frame along with the delay caused by the compensation process of compensation circuit **19**.

[0068] FIG. **6**B shows an example of a delay between sync signal **5** and external IF output timing signal **22**. Here, external IF output timing signal **22** shown in FIG. **6**B is a signal that represents the update timing of external output image data. Due to this delay, when the external output image data that are output from THz camera **4** are supplied to CPU **14** in synchronization with sync signal **5**, an image that lies between frames or image data with a delay of a frame are obtained and thereby image data obtaining device **13** cannot accurately perform the image process as a problem that arises.

[0069] To solve this problem, according to this exemplary embodiment, phase compensation circuit **16** compensates the difference between the phase of sync signal **5** and the phase of the external output image data. Specifically, phase compen-

sation circuit **16** generates image obtaining timing signal **23** such that sync signal **5** delays for a predetermined time {(compensation process time of compensation circuit **19**)+(update time of buffer **20**)}. CPU **14** obtains external output image data from THz camera **4** based on image obtaining timing signal **23**.

[0070] Next, with reference to FIG. **7**A to FIG. **7**E, examples of methods in which CPU **14** disposed in image data obtaining device **13** stores image data captured during an ON period of THz light source (QCL) **1**, image data captured during an OFF period thereof, and image data representing the differences between their images to buffer **15**, will be described.

[0071] In a first method shown in FIG. **7**A, three types of buffers X, Y, and Z are prepared. Eight pieces of image data captured during an ON period of THz light source **1** are stored in eight buffer memories X_1~X_8 that compose buffer X; eight pieces of image data captured during an OFF period thereof are stored in eight buffer memories Y_1~Y_8 that compose buffer Y; and then image data representing the differences between their images are stored in eight buffer memories Z_1~Z_8 that compose buffer Z.

[0072] In a second method shown in FIG. **7**B, two types of buffers X and Y are prepared. Eight pieces of image data captured during an ON period of THz light source **1** are stored in eight buffer memories X_1~X_8 that compose buffer X; eight pieces of image data captured during an OFF period are stored in eight buffer memories Y_1~Y_8 that compose buffer Y; and then image data representing the differences between their images are stored in the eight buffer memories X_1~X_8 that compose buffer X again.

[0073] In a third method shown in FIG. **7**C, two types of buffers are prepared. Eight pieces of image data captured during an ON period of THz light source **1** are stored in eight buffer memories X_1~X_8 that compose buffer X; eight pieces of image data captured during an OFF period are stored in eight buffer memories Y_1~Y_8 that compose buffer Y; and then image data representing the differences between their images are stored in eight buffer memories Y_1~Y_8 that compose buffer Y again.

[0074] In a fourth method shown in FIG. **7**D, two types of buffers X and Y are prepared. However, although the number of buffer memories that compose one buffer X is eight, as in the foregoing second and third methods, the number of buffer memories that compose the other buffer Y is two, unlike the foregoing second and third methods. In other words, eight pieces of image data captured during an ON period of THz light source **1** are stored in eight buffer memories X_i (where i=1, 2, . . . , 8) that compose buffer X. Thereafter, a first piece of image data captured during an OFF period is stored in first buffer memory Y_1 that composes buffer Y, the difference between the first piece of image data captured during the OFF period and the first piece of image data captured during the ON period is calculated and then image data representing the difference between images is stored in first buffer memory X_1 that composes buffer X. While the calculation and storing procedures are being performed, a second piece of image data captured during the OFF period is stored in second buffer memory Y_2 that composes buffer Y, the difference between the second piece of image data captured during the ON period and the second piece of image data captured during the OFF period is calculated, and then image data representing the difference between images are stored in second buffer memory X_2 that composes buffer X. This calculation and storing procedures are performed alternately using two buffer memories Y_1 and Y_2 that compose buffer Y. As a result, calculation results of $X_{2n+1}-Y_1$ (where n=0, 1, 2, 3) are stored in X_{2n+1}, whereas the calculation results of $X_{2n}-Y_2$ (where n=1, 2, 3, 4) are stored in X_{2n}.

[0075] In a fifth method shown in FIG. **7**E, eight pieces of image data captured during an ON period of THz light source **1** and eight pieces of image data captured during an OFF period thereof are stored in buffer **1** and image data representing the differences between their images are stored in buffer **2**.

[0076] CPU **14** integrates image data representing the difference between images obtained as described above and displays integrated image data representing the difference between images.

[0077] Alternatively, CPU **14** may perform a method in which image data are integrated before differences between images are obtained instead of a method in which image data are integrated after image data representing differences between images are obtained.

[0078] In other words, CPU **14** integrates a plurality of pieces of image data captured during an ON period of THz light source (QCL) **1**, integrates a plurality of pieces of image data captured during an OFF period thereof, calculates the differences between the integrated image data of the plurality of pieces of image data captured during the ON period and the integrated image data of the plurality of pieces of image data captured during the OFF period, and then displays the difference between images of the integrated image data.

[0079] With reference to FIG. **7**F, such an example in which image data captured during an ON period of THz light source (QCL) **1** and image data captured during an OFF period thereof are stored in buffer **15** disposed in image data obtaining device **13** will be described.

[0080] However, CPU **14** cannot simultaneously perfoim a method in which image data are integrated after image data representing the differences between images are obtained and a method in which image data are integrated before image data representing the differences between images are obtained. Thus, one of these methods needs to have been set for CPU **14**.

[0081] In the method shown in FIG. **7**F, two types of buffers X and Y are prepared. Eight pieces of image data captured during an ON period of THz light source **1** are stored in eight buffer memories X_1~X_8 that compose buffer X and then eight pieces of image data captured during an OFF period thereof are stored in eight buffer memories Y_1~Y_8 that compose buffer Y.

[0082] Next, with reference to FIG. **8**, FIG. **9**, and FIG. **10**, an example in which integrated image data representing the differences between images are calculated in the foregoing manner and thereby the signal-to-noise is improved two to three times compared to the related art will be described. In the following, it is assumed that image data are integrated before image data representing the differences between images are obtained.

[0083] As shown in FIG. **8**, sample **3** in which black cloth tape **25** is adhered on an Al tape coated on reflection plate **24** is prepared. An emission line at a frequency of 3.1 THz that is emitted by THz light source (QCL) **1** that is cooled by liquid nitrogen is radiated to partial region **26** of reflection plate **24**. A reflection image whose emission line has been reflected by reflection plate **24** is captured by THz camera **4** that is pro-

vided with THz array sensor **17** that have 320 * 240 pixels arranged at a pitch of 23.5 μm.

[0084] FIG. **9** is a reflection image of an emission line emitted by THz light source (QCL) **1** and reflected by reflection plate **24** (the reflection image is depicted as an elongated portion nearly at the center of the figure). The reflection image is formed in an elongated shape because an off-axis parabolic mirror (not shown) disposed in THz light source (QCL) **1** has an aberration. Since the reflectance of black cloth tape **25** is low, low luminance portion **27** appears nearly at the center of the elongated portion. Low luminance portion **27** corresponds to position **28** of cloth tape **25**.

[0085] FIG. **9** shows a difference in an image in which the difference between an integrated image of seven pieces of the second to the eighth piece of image data captured during an ON period of THz light source **1** and an integrated image of seven pieces of the second to the eighth piece of image data captured during an OFF period thereof is calculated at a lock-in frequency of 3.75 Hz. The first piece of image data is not used taking account of the fact that the time constant of THz array sensor **17** is 16 msec and thereby a signal of the first frame might have been not fully raised or lowered during the ON period or OFF period of THz light source (QCL) **1**. In this case, image data are stored in buffer **15** based on the method shown in FIG. **7**F. In addition, image data of 24 * 24 pixels are integrated so as to further improve the signal-to-noise ratio. The signal-to-noise ratio of high luminance portion **29** on the right of a QCL image shown in FIG. **9** is around 400.

[0086] FIG. **10** shows a difference in an image between one piece of image data captured during an ON period of THz light source (QCL) **1** and one piece of image data captured during an OFF period thereof so as to check out how the present invention improves the signal-to-noise ratio compared to the related art. This difference in the image corresponds to an image obtained based on a function of the image capturing device according to the related art. Sample **3** is the same as the sample from which the image shown in FIG. **9** is captured. The shape of the image shown in FIG. **10** is the same as that shown in FIG. **9**. The lock-in frequency at which the differences between image shown in FIG. **10** is obtained is also 3.75 Hz. The signal-to-noise ratio of high luminance portion **29** on the right of a QCL image shown in FIG. **10** is around 135.

[0087] Thus, it is clear that the present invention (shown in FIG. **9**) can improve the signal-to-noise ratio two to three times compared to the related art (shown in FIG. **10**).

[0088] With reference to the exemplary embodiments, the present invention has been described. However, it should be understood by those skilled in the art that the structure and details of the present invention may be changed in various manners without departing from the scope of the present invention.

[0089] According to foregoing exemplary embodiments, successive seven pieces from among all eight pieces of image data captured during ON/OFF periods of THz light source **1** were used. Alternatively, as long as the time constant of THz array sensor **17** is low, all eight pieces of image data may be used. Alternatively, seven pieces from the first to the seventh piece of image data may be used. In other words, according to the present invention, a plurality of successive pieces from among all pieces of image data captured during the ON/OFF periods of THz light source **1** may be selected and used.

[0090] In addition, according to a foregoing exemplary embodiment, a reflection image reflected by sample **3** was obtained. Alternatively, a transmission image that transmits through sample **3** may be obtained.

[0091] In addition, the foregoing exemplary embodiments deal with electromagnetic waves of a THz frequency band. Alternatively, the present invention can be applied to electromagnetic waves of other frequency bands as well as such a frequency band.

[0092] The whole or part of the exemplary embodiments disclosed above can be described as but not limited to, the following supplementary notes.

[Supplementary Note 1]

[0093] An image capturing device having a light source and a camera that captures an image of a measurement subject placed in an optical path that lies between said camera itself and said light source, comprising:

[0094] a control unit that subtracts a plurality of frame images captured by said camera during an OFF period of said light source from a plurality of frame images captured by said camera during an ON period of said light source, the number of frame images captured by said camera during the OFF period being the same as that number of frame images obtained by said camera during the ON period and integrates the differences between their images.

[Supplementary Note 2]

[0095] The image capturing device as set forth in supplementary note 1,

[0096] wherein said control unit stores a plurality of frame images captured by said camera during the ON period of said light source in a first buffer,

[0097] wherein said control unit stores a plurality of frame images captured by said camera during the OFF period of said light source in a second buffer,

[0098] wherein said control unit subtracts the plurality of frame images stored in said second buffer from the plurality of frame images stored in said first buffer and stores the differences between their images in a third buffer, the number of frame images stored in said second buffer being the same as the number of frame images stored in said first buffer, and

[0099] wherein said control unit integrates the differences between images stored in said third buffer.

[Supplementary Note 3]

[0100] The image capturing device as set forth in supplementary note 2,

[0101] wherein said control unit selects any successive frame images from among all the frame images captured by said camera during the ON period of said light source, and

[0102] wherein said control unit selects successive frame images from among all frame images captured by said camera during the OFF period of said light source, the successful number of frame images selected from among all frame images captured during the ON period being the same as the successive number of frame images selected from among all frame images captured during the OFF period.

[Supplementary Note 4]

[0103] The image capturing device as set forth in supplementary note 2 or 3,

[0104] wherein said control unit uses said first buffer or said second buffer as said third buffer.

[Supplementary Note 5]

[0105] The image capturing device as set forth in supplementary note 1,

[0106] wherein said control unit stores a plurality of frame images captured by said camera during the ON period of said light source and a plurality of frame images captured by said camera during the OFF period of said light source in a first buffer, the number of frame images captured by said camera during the ON period of said light source being the same as the number of frame images captured by said camera during the OFF period of said light source,

[0107] wherein said control unit subtracts the plurality of frame images captured by said camera during the OFF period of said light source and stored in said first buffer from the plurality of frame images captured by said camera during the ON period of said light source and stored in said first buffer and stores the differences between their images in said second buffer, the number of frame images captured by said camera during the OFF period of said light source and stored in said second buffer being the same as the number of frame images captured by said camera during the ON period of said light source and stored in said first buffer, and

[0108] wherein said control unit integrates the differences between images stored in said second buffer.

[Supplementary Note 6]

[0109] An image capturing device having a light source and a camera that captures an image of a measurement subject placed in an optical path that lies between said camera itself and said light source, comprising:

[0110] a control unit that integrates a plurality of frame images captured by said camera during an ON period of said light source, integrates a plurality of frame images captured by said camera during an OFF period of said light source, the number of frame images captured by said camera during the ON period being the same as the number of frame images captured by said camera during the OFF period, subtracts an integrated image of the frame images captured by said camera during the OFF period of said light source from an integrated image of the frame images captured by said camera during the ON period of said light source, and obtains the difference between their images.

[Supplementary Note 7]

[0111] The image capturing device as set forth in supplementary note 6,

[0112] wherein said control unit selects any successive frame images from among all the frame images captured by said camera during the ON period of said light source and integrates the selected frame images, and

[0113] wherein said control unit selects successive frame images from among all the frame images captured by said camera during the OFF period of said light source, the number of frame images captured by said camera during the OFF period being the same as the number of frame images captured by said camera during the ON period, and integrates the selected frame images.

[Supplementary Note 8]

[0114] The image capturing device as set forth in any one of supplementary notes 1 to 7, further comprising:

[0115] a first pulse circuit that generates a first pulse sequence;

[0116] a second pulse circuit that generates a second pulse sequence based on an image capturing timing signal that represents an image capturing timing of said camera, said second pulse sequence having a lower frequency than does the image capturing timing signal;

[0117] an AND circuit that perfonns an AND operation for said first pulse sequence and said second pulse sequence; and

[0118] a drive circuit that drives said light source based on a third pulse sequence that is a calculation result of the AND operation of said AND circuit.

[Supplementary Note 9]

[0119] The image capturing device as set forth in supplementary note 8,

[0120] wherein said second pulse circuit is capable of setting any frequency that is lower than the frequency of said image capturing timing signal and generates said second pulse sequence at the frequency that has been set.

[Supplementary Note 10]

[0121] The image capturing device as set forth in supplementary note 8 or 9, further comprising:

[0122] a phase compensation circuit that generates an image obtaining signal of which said image capturing timing signal is delayed for a predeteimined time,

[0123] wherein said control unit obtains frame images captured by said camera based on said image obtaining signal.

[Supplementary Note 11]

[0124] An image capturing method for an image capturing device having a light source and a camera that captures an image of a measurement subject placed in an optical path that lies between said camera itself and said light source, comprising:

[0125] subtracting a plurality of frame images captured by said camera during an OFF period of said light source from a plurality of frame images captured by said camera during an ON period of said light source, the number of frame images captured by said camera during the OFF period being the same as the number of frame images captured by said camera during the ON period, and integrating the differences between their images.

[Supplementary Note 12]

[0126] An image capturing method for an image capturing device having a light source and a camera that captures an image of a measurement subject placed in an optical path that lies between said camera itself and said light source, comprising:

[0127] integrating a plurality of frame images captured by said camera during an ON period of said light source;

[0128] integrating a plurality of frame images captured by said camera during an OFF period of said light source, the number of frame images captured by said camera during the OFF period being the same as the number of frame images captured by said camera during the ON period; and

[0129] subtracting an integrated image of the frame images captured by said camera during the OFF period of said light source from an integrated image of the frame images captured by said camera during the ON period of said light source and obtaining the differences between their images.

What is claimed is:

1. An image capturing device having a light source and a camera that captures an image of a measurement subject placed in an optical path that lies between said camera itself and said light source, comprising:

a control unit that subtracts a plurality of frame images captured by said camera during an OFF period of said light source from a plurality of frame images captured by said camera during an ON period of said light source, the number of frame images captured by said camera during the OFF period being the same as that number of frame images obtained by said camera during the ON period and integrates the differences between their images.

2. The image capturing device as set forth in claim **1**,

wherein said control unit stores a plurality of frame images captured by said camera during the ON period of said light source in a first buffer,

wherein said control unit stores a plurality of frame images captured by said camera during the OFF period of said light source in a second buffer,

wherein said control unit subtracts the plurality of frame images stored in said second buffer from the plurality of frame images stored in said first buffer and stores the differences between their images in a third buffer, the number of frame images stored in said second buffer being the same as the number of frame images stored in said first buffer, and

wherein said control unit integrates the differences between images stored in said third buffer.

3. The image capturing device as set forth in claim **2**,

wherein said control unit selects any successive frame images from among all the frame images captured by said camera during the ON period of said light source, and

wherein said control unit selects successive frame images from among all frame images captured by said camera during the OFF period of said light source, the successful number of frame images selected from among all frame images captured during the ON period being the same as the successive number of frame images selected from among all frame images captured during the OFF period.

4. The image capturing device as set forth in claim **2**,

wherein said control unit uses said first buffer or said second buffer as said third buffer.

5. The image capturing device as set forth in claim **1**,

wherein said control unit stores a plurality of frame images captured by said camera during the ON period of said light source and a plurality of frame images captured by said camera during the OFF period of said light source in a first buffer, the number of frame images captured by said camera during the ON period of said light source being the same as the number of frame images captured by said camera during the OFF period of said light source,

wherein said control unit subtracts the plurality of frame images captured by said camera during the OFF period of said light source and stored in said first buffer from the plurality of frame images captured by said camera during the ON period of said light source and stored in said first buffer and stores the differences between their images in said second buffer, the number of frame images captured by said camera during the OFF period of said light source and stored in said second buffer being the same as the number of frame images captured by said camera during the ON period of said light source and stored in said first buffer, and

wherein said control unit integrates the differences between images stored in said second buffer.

6. An image capturing device having a light source and a camera that captures an image of a measurement subject placed in an optical path that lies between said camera itself and said light source, comprising:

a control unit that integrates a plurality of frame images captured by said camera during an ON period of said light source, integrates a plurality of frame images captured by said camera during an OFF period of said light source, the number of frame images captured by said camera during the ON period being the same as the number of frame images captured by said camera during the OFF period, subtracts an integrated image of the frame images captured by said camera during the OFF period of said light source from an integrated image of the frame images captured by said camera during the ON period of said light source, and obtains the difference between their images.

7. The image capturing device as set forth in claim **6**,

wherein said control unit selects any successive frame images from among all the frame images captured by said camera during the ON period of said light source and integrates the selected frame images, and

wherein said control unit selects successive frame images from among all the frame images captured by said camera during the OFF period of said light source, the number of frame images captured by said camera during the OFF period being the same as the number of frame images captured by said camera during the ON period, and integrates the selected frame images.

8. The image capturing device as set forth in claim **1**, further comprising:

a first pulse circuit that generates a first pulse sequence;

a second pulse circuit that generates a second pulse sequence based on an image capturing timing signal that represents an image capturing timing of said camera, said second pulse sequence having a lower frequency than does the image capturing timing signal;

an AND circuit that performs an AND operation for said first pulse sequence and said second pulse sequence; and

a drive circuit that drives said light source based on a third pulse sequence that is a calculation result of the AND operation of said AND circuit.

9. The image capturing device as set forth in claim **8**,

wherein said second pulse circuit is capable of setting any frequency that is lower than the frequency of said image capturing timing signal and generates said second pulse sequence at the frequency that has been set.

10. The image capturing device as set forth in claim **8**, further comprising:

a phase compensation circuit that generates an image obtaining signal of which said image capturing timing signal is delayed for a predetermined time,

wherein said control unit obtains frame images captured by said camera based on said image obtaining signal.

11. An image capturing method for an image capturing device having a light source and a camera that captures an

image of a measurement subject placed in an optical path that lies between said camera itself and said light source, comprising:

subtracting a plurality of frame images captured by said camera during an OFF period of said light source from a plurality of frame images captured by said camera during an ON period of said light source, the number of frame images captured by said camera during the OFF period being the same as the number of frame images captured by said camera during the ON period, and integrating the differences between their images.

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